DOI: 10.22067/jacsm.2021.56463.0

Email: m.sharifian@qiet.ac.ir

[illegible] [16] [illegible] [17] [illegible] [18] [illegible] [19] [illegible] [7] [illegible]

[illegible] [8] [illegible] [9] [illegible] [10] [illegible] [11] [illegible] [12] [illegible]

[illegible] [15] [illegible] [14] [illegible]

$$\|\Sigma\| - R = 0$$

$$\Sigma = s - \alpha$$

$$\sigma = s + pi \quad p = \frac{1}{3}\mathrm{tr}(\sigma)$$

$$\varepsilon = e + \frac{1}{3}\theta i \qquad \theta = \mathrm{tr}(\varepsilon)$$

[20]

$$\dot{R} = \bar{b}(R_0 + R_s + R)\dot{\gamma}$$

$$R = R_0 + R_s[1 - \exp(-\bar{b}\gamma)]$$

$$e = e^p + e^e$$

$$\dot{\alpha} = H_{kin}\dot{\gamma}n - \dot{\gamma}H_{nl}\alpha$$

$$s = 2Ge^e = 2G(e - e^p)$$

$$\dot{\gamma} \geq 0 \quad F \leq 0 \quad \dot{\gamma}F = 0$$

$$\dot{F} = 0$$

$$\dot{e}^p = \dot{\gamma}n$$

$$\dot{\gamma} = \frac{2G(n^T\dot{e})}{2\bar{G} + \bar{b}(R_0 + R_s - R) - n^T H_{nl}\alpha}$$

$$n = \frac{\partial F}{\partial \Sigma} = \frac{\Sigma}{\|\Sigma\|} = \frac{\Sigma}{R}$$

$$\overline{2G} = 2G + H_{kin}$$

$$\dot{\bar{\Sigma}} = \frac{\dot{\Sigma}}{R} - \frac{R_s \bar{b}\exp(-\bar{b}\gamma)}{R}\dot{\gamma}\bar{\Sigma}$$

$$\dot{\bar{\Sigma}} + \left(\frac{2\bar{G} + R_s\bar{b}\exp(-\bar{b}\gamma)}{R}\right)\dot{\gamma}\bar{\Sigma} = \frac{2G}{R}\dot{\phi}$$

$$X^0\dot{\bar{\Sigma}} + X^0\left(\frac{2\bar{G} + R_s\bar{b}\exp(-\bar{b}\gamma)}{R}\right)\dot{\gamma}\bar{\Sigma} = \frac{d}{dt}(X^0\bar{\Sigma})$$

$$\dot{X}^0 = \left(\frac{2\bar{G} + R_s\bar{b}\exp(-\bar{b}\gamma)}{R}\right)\dot{\gamma}X^0$$

$$X^0(0) = 1$$

$$X(\gamma) = \begin{cases} \left(\frac{(R_0 + R_s)\exp(\bar{b}\gamma) - R_s}{R_0}\right)^{1/\beta}\exp(-b\gamma); & \bar{b} \neq 0 \\ \exp\left(\frac{2\bar{G}}{R_0}\gamma\right) & \bar{b} = 0 \end{cases}$$

$$\beta = \frac{\bar{b}(R_0 + R_s)}{2\bar{G} + \bar{b}(R_0 + R_s)}$$

$$\frac{d}{dt}(X^0\bar{\Sigma}) = X^0\frac{2G}{R}\dot{\phi}$$

$$\frac{X^0}{2}\frac{d}{dt}\|\bar{\Sigma}\|^2 + \dot{X}^0\|\bar{\Sigma}\|^2 = \frac{2G}{R}\dot{\phi}^T(X^0\bar{\Sigma})$$

$$\dot{\Sigma} = 2G\dot{e} + H_{nl}\dot{\alpha} - 2\bar{G}\dot{e}^p$$

$$\dot{\Sigma} + 2\bar{G}\frac{\Sigma}{R}\dot{\gamma} = 2G\dot{\phi}$$

$$\dot{\phi} = \dot{e} + \frac{1}{2G}H_{nl}\dot{\alpha}$$

$$\bar{\Sigma} = \frac{\Sigma}{R}$$

$$\dot{X}^0 = \frac{2G}{R}\dot{\phi}^T(X^0\Sigma)$$

$$\frac{d}{dt}\begin{Bmatrix} X^0\Sigma \\ X^0 \end{Bmatrix} = \frac{2G}{R}\begin{bmatrix} \mathbb{0}_{9\times9} & \dot{\phi} \\ \dot{\phi}^T & 0 \end{bmatrix}_{10\times10}\begin{Bmatrix} X^0\Sigma \\ X^0 \end{Bmatrix}$$

$$X = \begin{Bmatrix} X^0\Sigma \\ X^0 \end{Bmatrix} = \begin{Bmatrix} X^s \\ X^0 \end{Bmatrix}$$

$$\mathbb{B} = \frac{2G}{R}\begin{bmatrix} \mathbb{0}_{9\times9} & \dot{\phi} \\ \dot{\phi}^T & 0 \end{bmatrix}_{10\times10}$$

$$\dot{X} = \mathbb{B}X$$

$$X_n = \begin{Bmatrix} X_n^s \\ X_n^0 \end{Bmatrix}$$

$$X_{n+1} = \exp(\mathbb{B}\Delta t)\, X_n$$

$$\mathbb{B} = \frac{2G}{R}\begin{bmatrix} \mathbb{0}_{9\times9} & \dot{e} \\ 0^T & 0 \end{bmatrix}_{10\times10}$$

$$X_{n+1} = \exp(\mathbb{B}_n\Delta t)\, X_n = \bar{\mathbb{G}}_n X_n$$

$$\bar{\mathbb{G}}_n = \begin{cases} \bar{\mathbb{G}}_e = \begin{bmatrix} \mathbb{I}_{9\times9} & \frac{2G}{R_n}\Delta e \\ 0 & 1 \end{bmatrix} \\ \bar{\mathbb{G}}_p = \begin{bmatrix} \mathbb{I}_{9\times9} + (a-1)\Delta\hat{\phi}\Delta\hat{\phi}^T & b\Delta\hat{\phi}^T \\ b\Delta\hat{\phi}^T & a \end{bmatrix} \end{cases}$$

$$\|X^s\|^2 = (X^0)^2$$

$$(X^s)^T\dot{e} > 0$$

$$\alpha = \frac{\sqrt{C^2 - DM} - C}{D}$$

$$\begin{cases} D = \left(\frac{2G}{R_n}\mathbf{X}_n^0\|\Delta\mathbf{e}\|\right)^2 \\ C = \frac{2G}{R_n}\mathbf{X}_n^0(\mathbf{X}_n^0)^T\Delta\mathbf{e} \\ M = \|\mathbf{X}_n^s\|^2 - \|\mathbf{X}_n^0\|^2 \end{cases}$$

$$\mathbf{X}^c = \mathbb{G}^c\mathbf{X}^n$$

$$\mathbb{G}^c = \begin{bmatrix} \mathbb{I}_{9\times9} & \frac{2G}{R_n}\alpha\Delta\mathbf{e} \\ \mathbf{0}^T & 1 \end{bmatrix}$$

(1-α)Δe

$$\bar{\mathbb{G}}_n = \begin{cases} \bar{\mathbb{G}}_\mathbf{e} = \begin{bmatrix} \mathbb{I}_{9\times9} & \frac{2G}{R_n}\alpha\Delta\mathbf{e} \\ \mathbf{0} & \mathbf{1} \end{bmatrix} \\ \bar{\mathbb{G}}_\mathbf{p} = \begin{bmatrix} \mathbb{I}_{9\times9} + (a-1)\Delta\hat{\boldsymbol{\phi}}\Delta\hat{\boldsymbol{\phi}}^T & b\Delta\hat{\boldsymbol{\phi}}^T \\ b\Delta\hat{\boldsymbol{\phi}}^T & a \end{bmatrix} \end{cases}$$

$$\Delta\boldsymbol{\phi} = (1-\alpha)\Delta\mathbf{e} + \mathbf{u}\frac{\mathbf{n}_\mathbf{n}^T(1-\alpha)\Delta\mathbf{e}}{2\bar{G} + \bar{b}(R_s + R_0 - R_n)\mathbf{n}_\mathbf{n}^T H_{nl}\boldsymbol{\alpha}_n} H_{nl}\boldsymbol{\alpha}_n$$

$$\Delta\boldsymbol{\phi} = \Delta\mathbf{e} + \mathbf{u}\frac{\mathbf{n}_n^T\Delta\mathbf{e}}{2\bar{G} + \bar{b}(R_s + R_0 - R_n)\mathbf{n}_n^T H_{nl}\boldsymbol{\alpha}_n} H_{nl}\boldsymbol{\alpha}_n$$

$$a = \cosh g \quad b = \sinh g$$

$$g = \frac{2G}{R_n}\|\Delta\boldsymbol{\phi}\|$$

$$\Delta\hat{\phi} = \frac{\Delta\phi}{\|\Delta\phi\|}$$

$$\gamma_{n+1} = \gamma_n + \frac{2G(\mathbf{n}_n^T\Delta\mathbf{e})}{2\bar{G} + \bar{b}(R_s + R_0 - R_n)\mathbf{n}_n^T H_{nl}\boldsymbol{\alpha}_n}$$

$$R_{n+1} = R_0 + R_s[1 - \exp(-\bar{b}\gamma_{n+1})]$$

$$\mathbf{X}_{n+1}^{Tr} = \mathbb{G}^e\mathbf{X}_n$$

$$\|\mathbf{X}_{n+1}^{s,Tr}\| \leqslant X_{n+1}^{0,Tr}$$

$$\gamma_{\mathbf{r}} = \gamma_{\mathbf{n}} + \frac{2G\mathbf{n}_{\mathrm{r}}^{\mathrm{T}} r(1-\alpha)\Delta\mathbf{e}}{2\bar{G} + \bar{b}(R_{\mathrm{s}} + R_0 - R_{\mathrm{c}}) - \mathbf{n}_{\mathrm{r}}^{\mathrm{T}} H_{\mathrm{nl}}\boldsymbol{\alpha}_r}$$

$$R_{\mathrm{r}} = R_{\mathrm{n}+\alpha+\mathrm{r}(1-\alpha)} = R_{\mathbf{0}} + R_{\mathrm{s}}\left[1 - \exp(-\bar{b}\gamma_{\mathbf{r}})\right]$$

$$\Delta\mathbf{e}_{\mathrm{r}}^{\mathrm{p}} = \lambda_{\mathrm{r}}\mathbf{n}^{\mathrm{c}}$$

$$\mathbf{n}^{\mathrm{c}} = \frac{\xi_{\mathrm{c}}}{\|\xi_{\mathrm{c}}\|} = \frac{\mathbf{X}_{\mathrm{c}}^{\mathrm{s}}}{\mathrm{X}_0}$$

$$\mathbf{s}_{\mathrm{r}} = \mathbf{s}^{\mathrm{c}} + 2Gr(1-\alpha)\Delta\mathbf{e} - 2G\Delta\mathbf{e}_{\mathrm{r}}^{\mathrm{p}}$$

$$\boldsymbol{\Sigma}_{\mathrm{r}} = \mathbf{s}_{\mathrm{r}} - \boldsymbol{\alpha}_{\mathrm{r}}$$

$$\mathbb{G}_{\mathrm{p}} = \begin{bmatrix} \mathbb{I}_{9\times 9} + (a-1)\Delta\bar{\boldsymbol{\phi}}\Delta\bar{\boldsymbol{\phi}}^{\mathrm{T}} & b\Delta\bar{\boldsymbol{\phi}} \\ b\Delta\bar{\boldsymbol{\phi}}^{\mathrm{T}} & a \end{bmatrix}$$

$$\Delta\phi = (1-\alpha)\Delta\mathrm{e} + \frac{\mathbf{n}_{\mathrm{r}}^{\mathrm{T}}(1-\alpha)\Delta\mathbf{e}}{\bar{\mathrm{b}}(\mathrm{R_s} + \mathrm{R_0} - \mathrm{R_r}) - \mathbf{n}_{\mathrm{r}}^{\mathrm{T}}\mathrm{H_{nl}}\boldsymbol{\alpha}_{\mathrm{r}}}\mathrm{H_{nl}}\boldsymbol{\alpha}_{\mathrm{r}}$$

$$\mathrm{g} = \frac{2G}{R_{\mathrm{r}}}\|\Delta\boldsymbol{\phi}\|$$

$$\mathrm{a} = \cosh \mathrm{g}$$

$$a = \cosh g \quad b = \sinh g \quad g = \frac{2G}{R_{\mathrm{n}}}\|\Delta\boldsymbol{\phi}\|$$

$$\Delta\hat{\boldsymbol{\phi}} = \frac{\Delta\boldsymbol{\phi}}{\|\Delta\boldsymbol{\phi}\|}$$

$$\mathbf{X}_{\mathrm{n}+1} = \mathbb{G}_{\mathrm{n}}\mathbf{X}_{\mathrm{n}}$$

$$\mathbf{n}_{\mathrm{n}+\alpha+\mathrm{r}(1-\alpha)} = \frac{\boldsymbol{\Sigma}_{\mathrm{n}+\alpha+\mathrm{r}(1-\alpha)}}{\|\boldsymbol{\Sigma}_{\mathrm{n}+\alpha+\mathrm{r}(1-\alpha)}\|}$$

$$\boldsymbol{\alpha}_{\mathrm{r}} = \boldsymbol{\alpha}_{\mathrm{n}+\alpha+\mathrm{r}(1-\alpha)} = \mathrm{H_{kin}H_{nl}}\mathbf{n}_{\mathrm{c}} - \mathrm{H_{nl}}\lambda_{\mathrm{r}}\boldsymbol{\alpha}_{\mathrm{n}} + \boldsymbol{\alpha}_{\mathrm{n}}$$

[22] Carbon Steel CK15

$b = \sinh g$

$E = 2800\ \text{MPa} \quad H_{kin} = \frac{2}{3} \times 1900\ \text{MPa}$

$H_{nl} = \sqrt{\frac{2}{3}} \times 8.5 \quad R_0 = \sqrt{\frac{2}{3}} \times \sigma_{y,0} = \sqrt{\frac{2}{3}} \times 300 \quad \bar{b} = 10 \quad R_s = 25 \quad \nu = 0.3$

Chromium-nickel

[13] Stainless Steel X5CRNR18.9

$E = 2800\ \text{MPa} \quad \nu = 0.3 \quad H_{nl} = 525 \quad \bar{b} = 0$

$R_0 = \sqrt{\frac{2}{3}} \times \sigma_{y,0} = \sqrt{\frac{2}{3}} \times 170, \; R_s = 0$

$H_{kin} = 41080\ \text{MPa}$

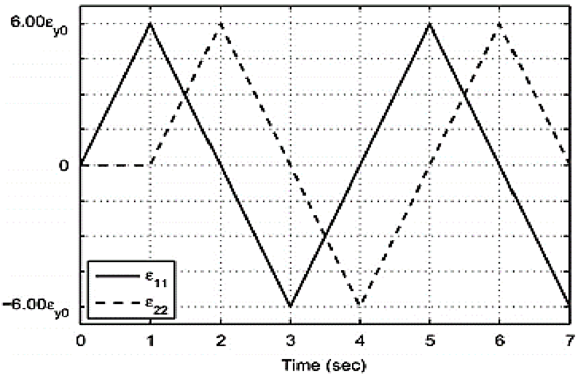
x_{n+1}

Chromium-nickel

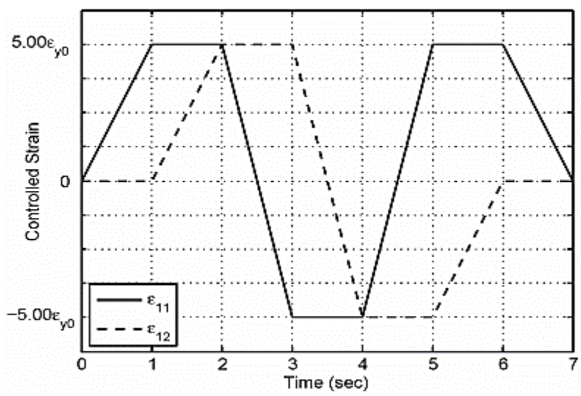
Carbon Steel Stainless Steel X5CRNR18.9

CK15

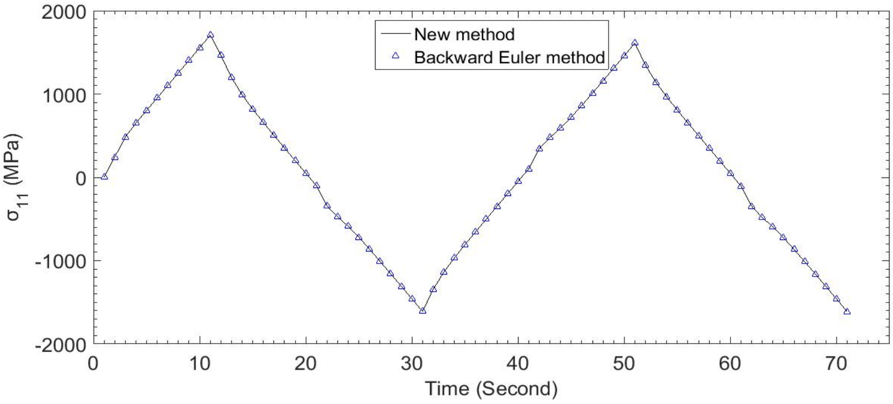
ε_{12} ε_{11}



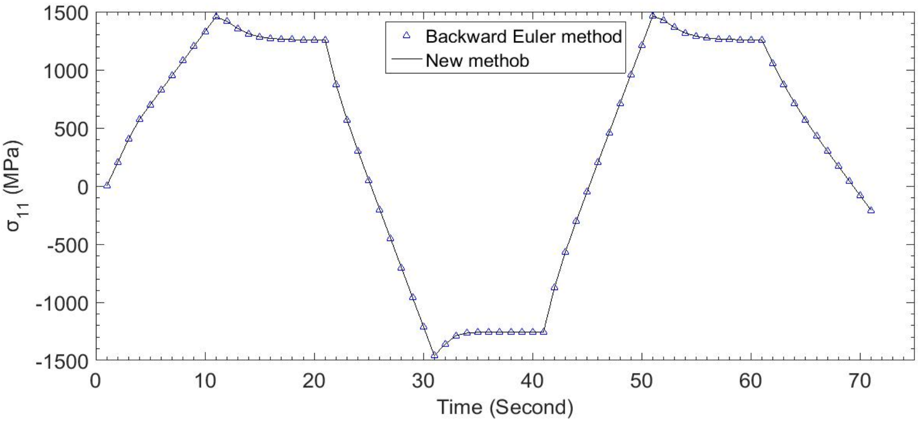
[23]



[8]



Carbon Steel CK15

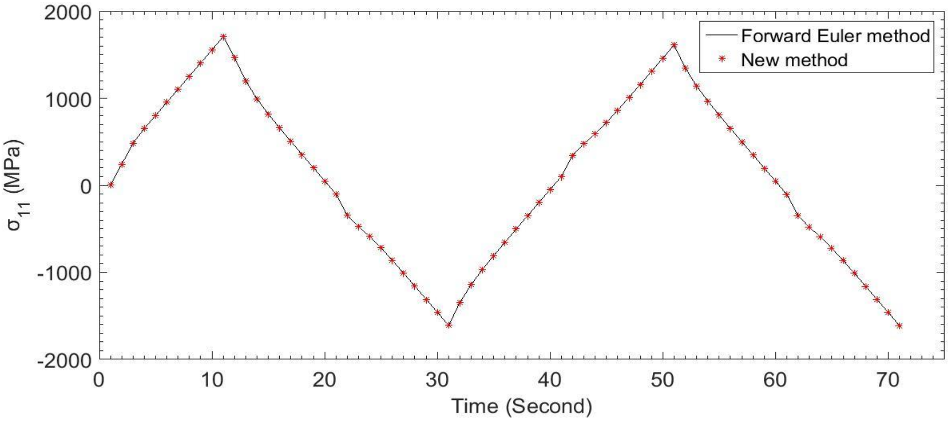


Carbon Steel CK15

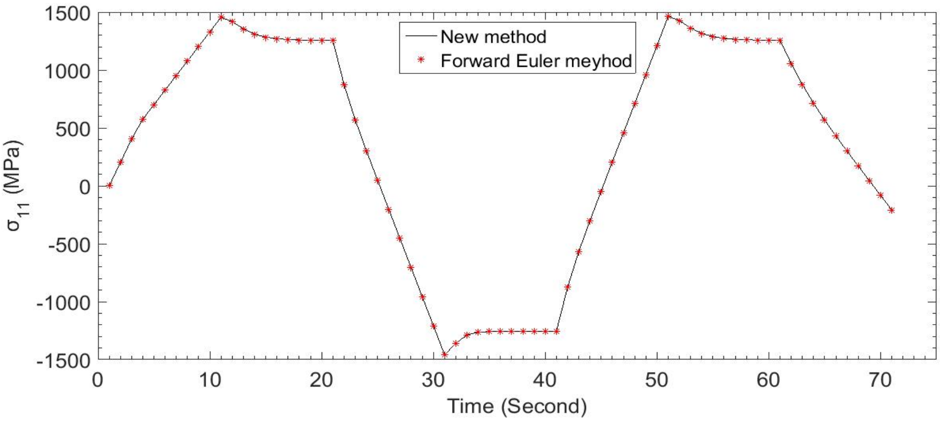
$\Delta t = 0.01$ sec

$\Delta t = 0.025$ sec

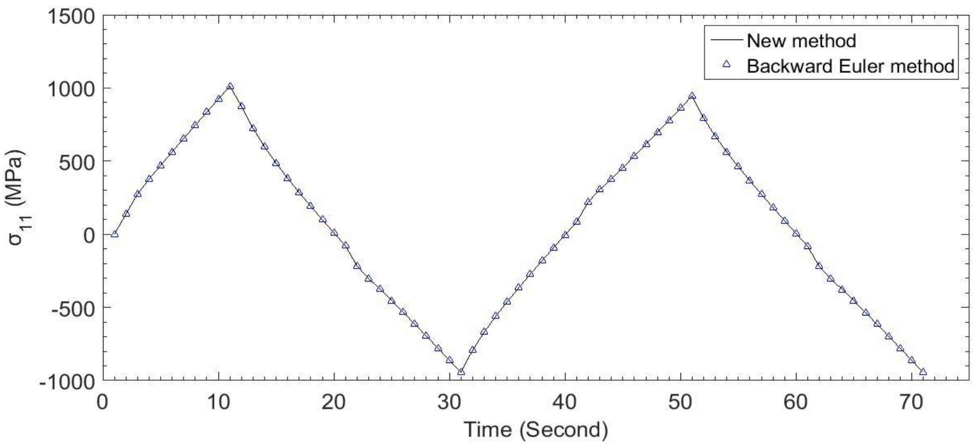
$$E_{\mathrm{n}}^{\sigma} = \frac{\|\boldsymbol{\sigma}_{\mathrm{n}} - \bar{\boldsymbol{\sigma}}_{\mathrm{n}}\|}{\|\bar{\boldsymbol{\sigma}}_{\mathrm{n}}\|}$$



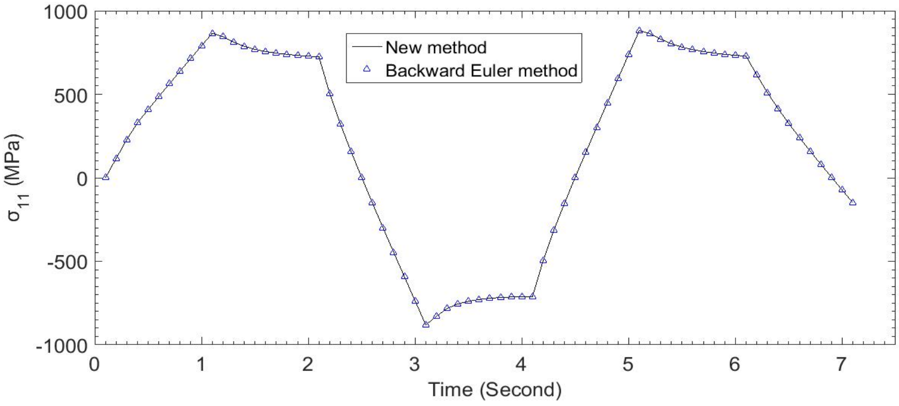
Carbon Steel CK15 ą ¹ w ù ½ ¹ ¢ Æ ¸ ý È ý ¾ í ¾ Ċ Æ ù 0 ŵ ẑ É º ĉ º « Ç ÿ ½ ÿ ÿ



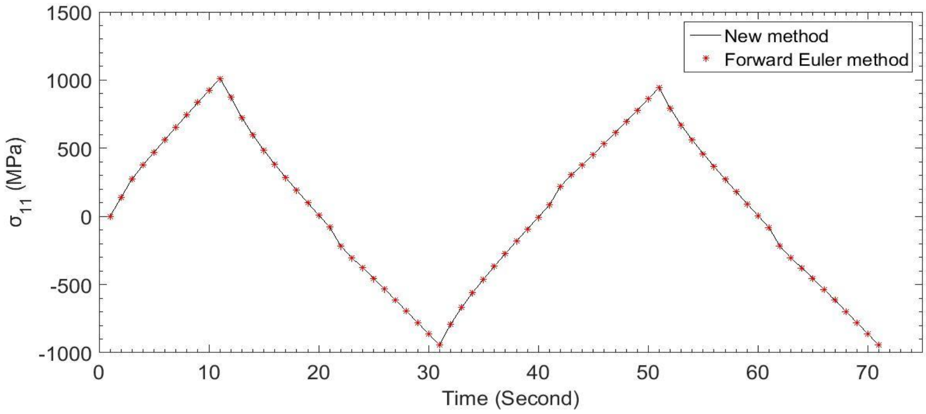
÷ ÿ È ¹ ý ¾ Ċ w Æ ù Carbon Steel CK15 ą ¹ w ù ½ ¹ º ĉ º « Ç Æ ÿ ĉ ¹ ŵ ê ĩ ÿ É ÿ ¾ Ê Ċ ~ ¾ õ ÿ v Ç ÿ ½



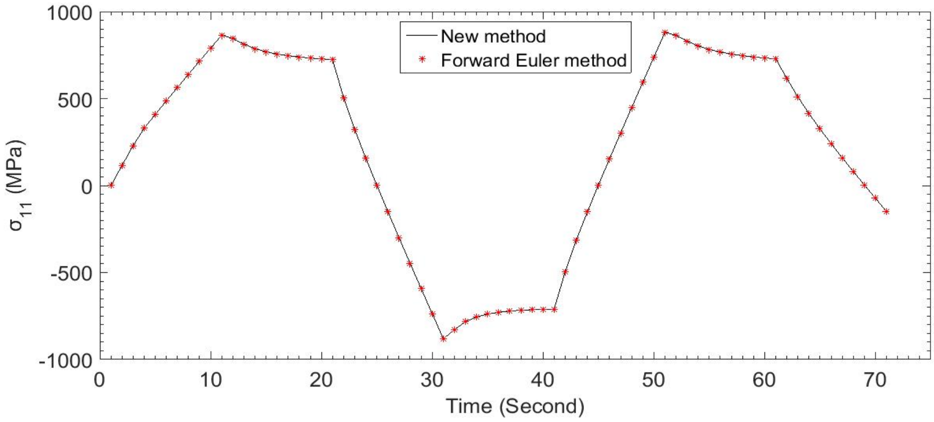
Chromium-nickel Stainless Steel X5CRNR18.9 ą ¹ w ù ½ ¹ ¢ Æ ¸ ý È ý ¾ í ¾ Ċ Æ 2 ù ô ŵ É º ĉ º « Ç



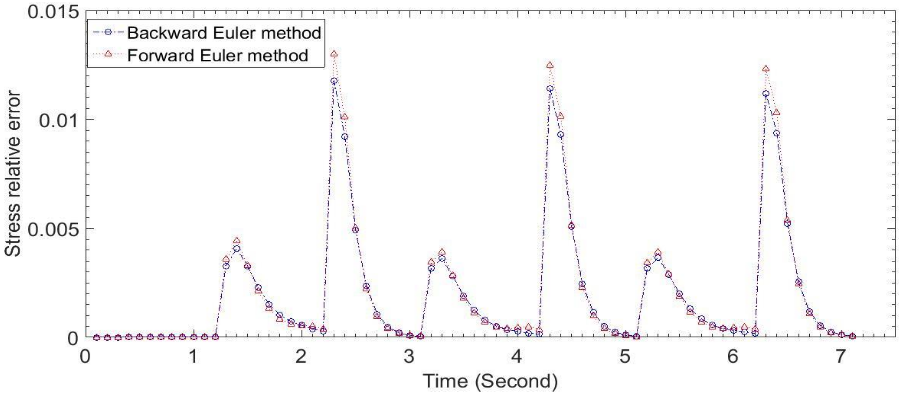
Chromium-nickel Stainless Steel X5CRNR18.9



Chromium-nickel Stainless Steel X5CRNR18.9



Chromium-nickel Stainless Steel X5CRNR18.9



Carbon Steel CK15

Carbon Steel CK15

t_n

$\Delta t = 0.001$ sec

$$E_T^{\sigma} = \sum \frac{\|\boldsymbol{\sigma}_n - \bar{\boldsymbol{\sigma}}_n\|}{\|\bar{\boldsymbol{\sigma}}_n\|}$$

r=0.5 Δt=0.01, 0.025, 0.05, 0.1 sec